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Evaluating the Effect of Absolute and Barometric Pressures on Borehole Performance in Tolon and Wa West Districts of Northern Ghana

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ABSTRACT

Groundwater is a very important asset to the people of Northern Ghana where majority are farmers as its used for many domestic and agricultural activities. The research evaluated the effects of absolute and barometric pressures on water-table fluctuations of boreholes in Wa West and Tolon Districts of Northern Ghana. Pumping tests, absolute and barometric pressures were monitored using non-vented water level sensors for one year, from 2015-2016. The results of the research indicate that, the aquifer of the Kpaligung borehole is of Voltaian province while that of Baleofili is Granitoid intrusions. The yield of the Baleofili borehole is 1.8 m3/h (30 l/min), while that of the Kpaligung borehole yields 1.4 m3/h (23 l/min). Rainfall regime has considerable effects on Kpaligung and Baleofili boreholes` recharge and water-table fluctuation due to the effects of both absolute and barometric pressure throughout the year. The relationship between barometric pressure and water pressure for the Kpaligung borehole shows positive, but weak correlation value (0.2) that is, increase in barometric pressure leads to an increase in water level and vice versa. The Baleofili borehole shows an inverse relationship between barometric pressure and water level pressure with the coefficient of correlation being 0.5. The relationship between the changes in water level of the boreholes with the corresponding change in rainfall amount suggests that the groundwater recharge of the boreholes depends considerably on annual rainfall variation in the study areas considered.

INTRODUCTION

Groundwater is frequently chosen as the most suitable source of drinking water, supplies of which are brought to the surface by rehabilitating existing boreholes or drilling new ones (Philippe, 2011). Groundwater serves as one of the most reliable sources of water for domestic and agricultural activities, especially where the yield is sustainable. According to Karikari (2000), the quality of groundwater in Ghana is generally good and accounts for a large share of the potable-water supply in rural communities, except in some few areas, like Bongo and Prestea, where the water contains iron, manganese and fluoride deposits. According to Brian *et al.* (2004), groundwater-levels are the most critical information collected about an aquifer indicating its hydrologic character and stresses. Water-level data are increasingly used by agencies to calibrate groundwater models and to design, implement, and monitor the effectiveness of groundwater management and conservation efforts. However, water-level data are often limited in frequency and geographic distribution for meaningful analyses.

Groundwater levels provide critical information about the hydrologic relationships of recharge and discharge to storage within an aquifer, and the direction of groundwater flow. Long-term, systematic measurements of water-level data are essential to develop groundwater models and to design, implement, and monitor the effectiveness of groundwater management programs (Taylor and Alley, 2001). Water level observations made during aquifer tests are susceptible to distortions due to the influence of fluctuations in barometric pressure. These distortions can be significant in aquifer test cases where interference due to pumping effects are small, because barometric pressure effects can make up a large proportion of the total observed water level fluctuations (Rasmussen and Crawford, 1997). It is therefore important to consider, and correct for, effects of barometric pressure changes when analysing aquifer test water level data.

The potential for barometric pressure changes to affect water levels has long been recognised (Quilty and Roeloffs, 1991). However, the practice of measuring high resolution barometric records has only really become common place with the use of electronic down-well pressure transducers with data logging capabilities, and that are not vented to the atmosphere (Quilty and Roeloffs, 1991). The pressure measurement recorded by an unvented pressure transducer is the total pressure, i.e. sum of standing head of water above the transducer plus the pressure induced by the atmosphere. In order for a non-vented logger record to represent changes in water levels (i.e. the actual water level record), the barometric pressure must be subtracted. According to Rasmussen and Crawford (1997), when water level records are compared to barometric pressure records some wells/aquifers exhibit a response to barometric change, i.e. a drop in barometric pressure may correspond to a rise in water levels.

The research evaluated the effects of absolute and barometric pressures on water level fluctuations of two boreholes in Wa West and Tolon Districts of Northern Ghana.

MATERIALS AND METHODS

Study Areas

The study was conducted in two administrative districts, Wa West in the Upper West Region where Baleofili is located and Tolon in the Northern Region of Ghana where Kpaligung is located. The districts studied are located in the Guinea Savannah belt of Ghana. The climate of the study areas follow a general pattern identified within the three regions of northern Ghana (Ghana Districts, 2006). It has a single rainy season from April to October/November, with average annual rainfall ranging between 950 mm - 1,200 mm (GSS, 2014). This is followed by a prolonged dry season, from early November to March. The mean day temperatures are ranging from 33°C to 39°C, while mean night temperature range from 20°C to 26°C. Before the onset of the rainy season, temperatures rise to their maximum (40 °C) and fall to minimum (20 °C) during `harmattan` period (January-February).

Tolon District

The Tolon District is in the Northern Region of Ghana, latitudes 9° 15′` and 10° 02` N and longitudes 0° 53′and 1° 25′ W. It shares boundaries to the north with Kumbungu, North Gonja to the west, Central Gonja to the south and Sagnarigu Districts to the east. The district is a particularly difficult place to find groundwater, as it is largely underlain by ancient, indurated sedimentary rocks of the Voltaian Supergroup, which were deposited in the northern part of the elongate, north to south trending Volta Basin in Neoproterozoic to early Palaeozoic times (Ó Dochartaigh *et al.,* 2011). Figure 1 presents the map of Tolon District where the Kpaligung`s community is located.

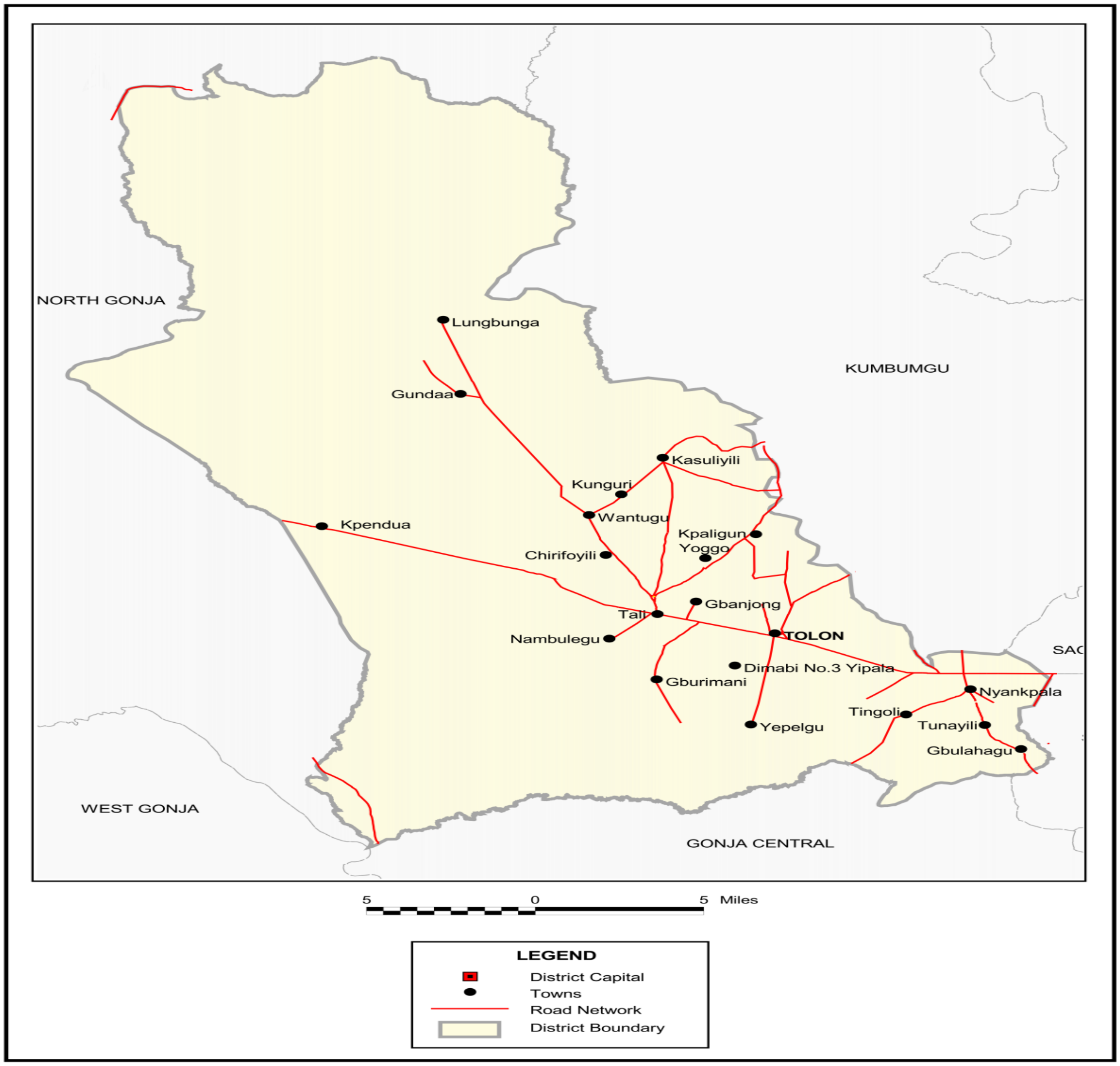

Figure 1: Map of Tolon District (GSS, 2014)

Wa West District

The Wa West District is located in the western part of the Upper West Region, approximately between longitudes 9º 40’ N and 10º 10’ N and also latitudes 2º 20’ W and 2º 50’ W. It shares boarders to the south with Northern Region, north-west by Nadowli District, east by Wa Municipal and to the west by Burkina Faso (GSS, 2014). This study was carried out at Baleofili community near Wichagu (see Map in Figure 2).

The topography of the Wa West District is gently rolling with a few hills ranging between 180 and 300 meters asl. It is drained by the Black Volta - to the west marking the boundary between the District and the Republic of Burkina Faso (GSS, 2014).

The geology of the study area is characterised by basement crystalline rocks derived from the Precambrian era and principally comprise the Birimian rocks and associated granitoid intrusions (Leube *et al.,* 1990; Taylor *et al.,* 1992; Hirdes *et al.,* 1992). The Birimian rocks include biotite and muscovite—bearing granite, granodiorite, diorite and gabbro, phyllites, schist, tuffs, basalt, sandstones, siltstones and strongly deformed metamorphic rocks (Nude and Arhin, 2009).

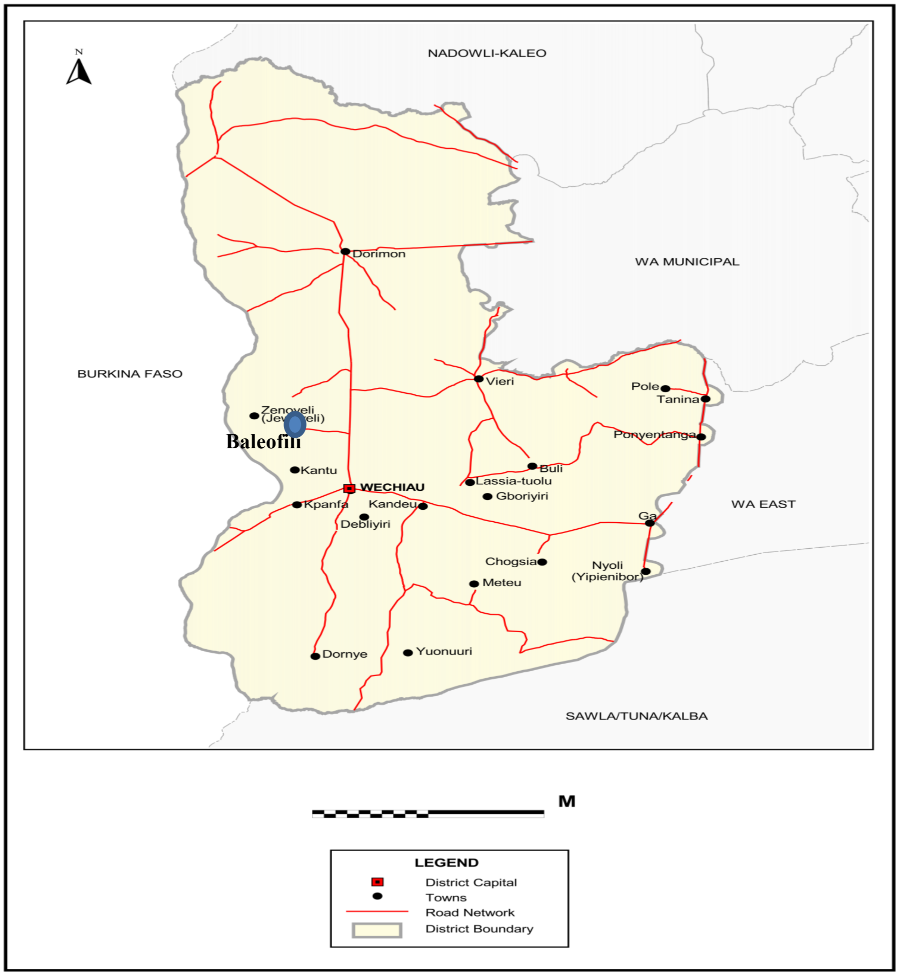

Figure 2: Map of Wa West District (GSS, 2014)

Materials and Equipment Used For the Studies

- Hand-held water-level monitor, commonly known as a “dipper” with dipper probe.
- ***Motorized pump:*** an electrical submersible pump (PEDROLLO) with 1 HP, discharge of 100 l/min and total head of 79 m was used to monitor the yields of the boreholes.
- ***Generator:*** a 6.5 HP, Tiger (TG 3700 E) petrol generator was used to provide electricity for the motorized pump.
- ***Rising main*****:** To carry the water up the borehole from a submersible pump, a flexible pipe of 100 meter long with 4.0 mm diameter was connected to the submersible pump.
- ***Manually-operated valves:*** 1`` (1 inch) manually operated valve was installed between the rising main and the discharge pipes to control the pumping rate.
- ***A stopwatch*** to measure the time of pumping and recovery

Methods

Drilling of the Boreholes and Conduction of Pumping Tests

A borehole each was drilled at Baleofili in Wa West District and Kpaligung in Tolon District in July 2015 by WATERSITES LTD from Tamale. Pumping test was carried out on both boreholes using constant-rate test method, to determine their yield and hydraulic properties of the aquifers. The aquifer types for both boreholes are unconfined, in which the water table forms the upper boundary of the water bearing formation.

A suitable local datum (such as the top of the casing) from which all water-level readings were taken was 45 cm and 90 cm respectively for the Kpaligung and Baleofili boreholes; the static water levels were 10.17 m and 12.45 m, respectively for the Kpaligung and Baleofili boreholes. The characteristics of the two boreholes are presented in Table 1.

Monitoring Water Levels using "Dipper"

The hand-held water-level monitor, commonly known as a "dipper" with dipper probe was lowered down the boreholes and when it reached the water surface, an electrical circuit is completed and a 'beep' sound was recorded. The water level was then read off from a graduated tape, to the nearest metre. This equipment was used to determine the static and dynamic water levels of the boreholes.

Monitoring Water Levels using HOBO Water Level Loggers

Pressure transducers (water level loggers) indirectly measure water level by measuring pressure due to an overlying fluid column (McDonald, 2011). At a point of measurement beneath the water surface in a well/borehole, the total pressure (absolute pressure) consists of two components: (I) water pressure and (2) atmospheric pressure at the water surface. Both of these result from fluid density, height of the fluid column above the point of measurement, and the acceleration due to gravity. According to McDonald (2011), to use a pressure transducer for water-level monitoring, some method of barometric compensation must be used to account for the atmospheric pressure component so only the water pressure component will be measured.

Automated water-level data was collected using absolute and barometric pressure monitoring sensors produced by HOBO by deploying the two sensors into the bore holes. The barometric sensor was placed at the water surface without touching the water since it was to record only atmospheric pressure - but the absolute pressure logger was submerged in the two boreholes to monitor both water and barometric pressures.

Figure 3 depicts a borehole with absolute (total pressure) and barometric (atmospheric) pressure loggers for both Kpaligung and Baleofili communities. The HOBO water level loggers were logged to monitor the boreholes at 30 minutes interval for one (1) year, starting from July 2015 to June 2016. These data loggers are ideal for recording water levels and temperatures in wells, streams, lakes, and freshwater wetlands. Plate 1 depicts the type of HOBO water level sensors used for the studies. The HOBO specification used for the water level monitoring was 0-3 m for barometric pressure and 0-9 m for absolute pressure. Data was downloaded using HOBO software installed in Windows and both graphs and MS Excel spread sheet of data were downloaded after every logged out.

Absolute Pressure Logger

Submersed absolute level-loggers (Plate 1) measure total pressure (water column equivalent + barometric pressure). In order to accurately determine the true changes in water level, barometric pressure fluctuations must be removed from the data (SOLINST, 2014).

Plate 1: HOBO Water Level Logger used for Absolute Pressure Monitoring

Barometric Pressure Logger

Barometric pressure applies a direct stress upon open wells/boreholes and surface water. Locally, barometric effects can change significantly from location to location as a result of topographical and micro-meteorological changes. Therefore, it is important to compensate for the barometric pressure changes when monitoring water elevation (In-Situ Inc., 2014)

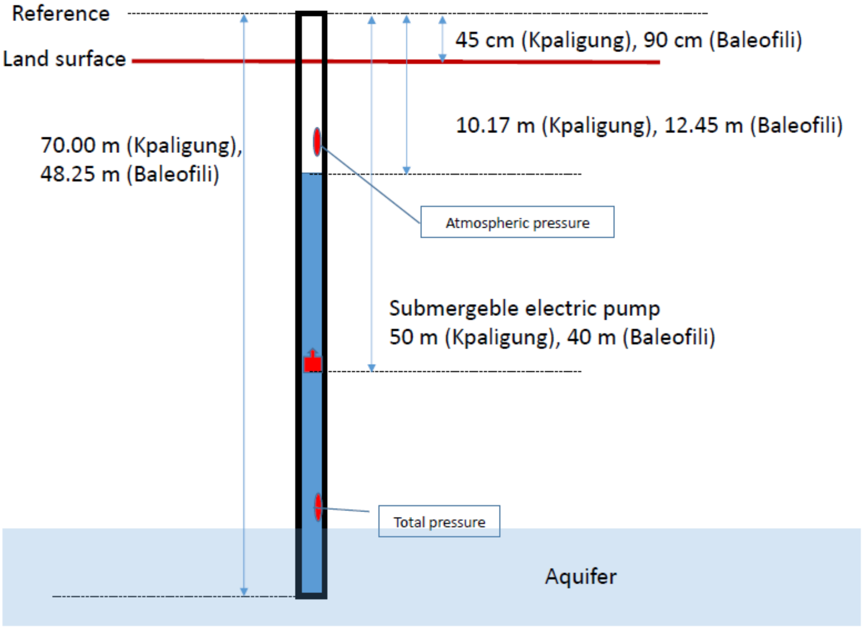

Figure 3: Borehole indicating the positions for Absolute (total pressure) and Barometric (ATP) sensors

Data Analysis

Analysis of HOBO Sensors Water Level Monitoring Data

The downloaded data from the absolute and barometric sensors from both boreholes were processed in MS Excel spread sheet by calculating average daily barometric and absolute pressure fluctuations. The data was further analysed to determine the water pressure by finding the difference between Absolute Pressure and Barometric Pressure (Equations 1 and 2).

$$\textit{Absolute Pressure} - \textit{Barometric Pressure} = \textit{Water Pressure} \qquad (1)$$

$$(P_{W+}P_{ATM}) - P_{ATM} = P_W \qquad (2)$$

Relationship between Rainfall Amount and Borehole Water Pressure (Head)

Historical monthly rainfall for forty Six years (1970-2016) of both Wa Municipality and Tolon District were analysed and plotted against monthly borehole water head (mm) of both Kpaligung and Baleofili borehole to ascertain the effect of rainfall on borehole recharge. Line graphs were plotted to show the effect of the rainfall regimes on boreholes water level variations.

RESULTS AND DISCUSSIONS

Characteristics of the Boreholes

Table 1 presents the characteristics of the two boreholes. For the Kpaligung borehole, the aquifer is of Voltaian province while that of Baleofili is of granitoid intrusions. According to Agyekum (2004), for areas underlain by granitoid intrusions, borehole depths are similar, ranging from 35 m to 55 m, for which the depth (48.25 m) the Baleofili borehole falls within. The borehole yields range from 0.3 m^3/h to 36.4 m^3/h with the average of 4 m^3/h. The yield of the Baleofili borehole is 1.8 m^3/h, implying that the Baleofili borehole yield is within the expected range. The low yield of boreholes in this formation, according to Martin (2006) could be attributed to differences in degree of weathering and fracturing. Even though the borehole yield is considered to be low, it is higher than that of the Kpaligung borehole, which yields 1.4 m^3/h.

The depth of the Kpaligung borehole is 70 m. According to Agyekum (2004), boreholes depths in the Voltaian province range from 45 m to 75 m, with the average of 55 m. However, the yield of the borehole was 1.4 m^3/d. This value is in the borehole yield range of (0.3 m^3/h to 72 m^3/h) with an average of 7.3 m^3/h indicated by Acheampong and Hess (1998) for the Voltaian province.

Table 1: Characteristics of the Studied Boreholes

Community	Datum Height above Ground Level (m)	Borehole Depth (m)	Pump Setting (m)	Static Water Level (m)	Borehole Yield (m^3/h)
Kpaligung	0.45	70.00	50	10.17	1.4
Baleofili	0.90	48.25	45	12.45	1.8

Effect of Constant Rate Pumping on Absolute Pressure

Figures 4 and 5 present the results of the pumping tests conducted in March and February 2016 for the Kpaligung and Baleofili boreholes respectively. The constant pumping rate of 23 l/min and 30 l/min respectively were used respectively for the Kpaligung and Baleofili boreholes while the water level sensors were submerged.

With respect to the Kpaligung borehole (Figure 4), as the pumping started at constant rate, the absolute pressure (kPa) also started reducing at a steep and fast rate from 238 kPa as the pumping continuous. From Figure 4, the steady state absolute pressure occurred when the absolute pressure reached 99.42 kPa, which is almost the same as the barometric pressure value of 99.25 kPa, after 2 hours of continued pumping of the borehole. This suggests that the borehole yield could be sustained even at a low water pressure (0.17 kPa) which is the difference between absolute and barometric pressure as pumping continuous. This could be attributed to the borehole receiving water from other aquifers from the surrounding boreholes.

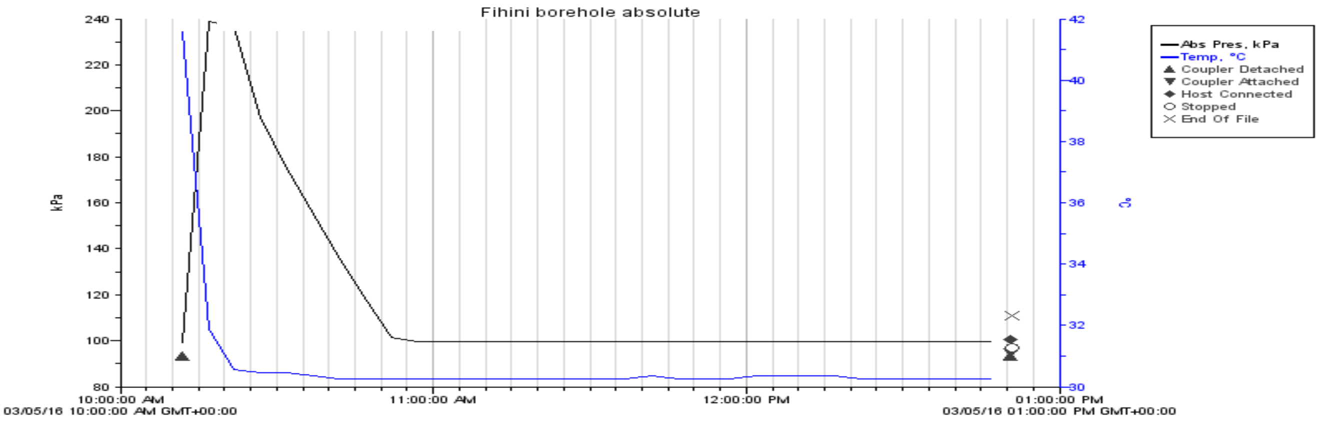

Figure 4: Effect of Constant Rate Pumping on Absolute Pressure for Kpaligung Borehole

Unlike the Kpaligung borehole (Figure 4), the Baleofili borehole (Figure 5) shows a sharp drop from 249.1 kPa to 179.6 kPa and again sharp increase to about 213 kPa and instantaneous drop about 180 kPa. From this stage, the absolute pressure gradually reduces and finally attained a steady state at an absolute pressure of 152 kPa, which is above the barometric pressure value of 98 kPa. This suggests that the borehole yield could be sustained as pumping continuous since the water pressure (water head) was high (54 kPa).

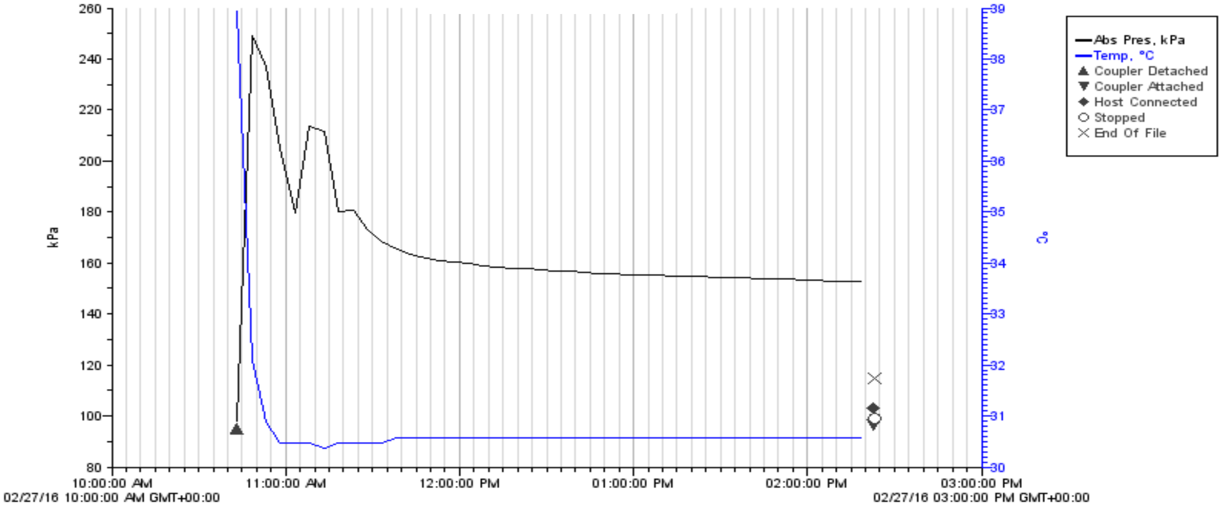

Figure 5: Effect of Constant Rate Pumping on Absolute Pressure for Baleofili Borehole

Effect of Rate of Borehole Recovery on Absolute Pressure

Figures 6 and 7 show the recovery tests conducted for the Kpaligung and the Baleofili boreholes using the HOBO water level sensors for absolute pressure monitoring.

With respect to the Kpaligung borehole, the absolute pressure recovery started when the pump was put off, while the sensor was already in the borehole and logged for the monitoring data to be recorded. As seen in Figure 6, the absolute pressure was fairly constant for 1 hour after pumping has been stopped. After that stage, the absolute pressure at recovery started to increase at an increasing rate for at least 30 minutes, after which it attained steady and constant pressure at 238 kPa, at which time the recovery was complete, two and half hours after pumping has stopped. The sharply increase in absolute pressure at an increasing rate could be attributed to the contribution of other groundwater sources of the other networks of boreholes to the aquifer of the borehole under study.

With respect to the Baleofili borehole (Figure 7), it indicates absolute pressure increasing at an increasing rate up to 130 kPa, after pumping has stopped for 30 minutes. After that point, there is a point of inflexion leading to gradual flattening of the graph as the absolute pressure getting steady at an absolute pressure of 190 kPa, which was attained after 2 hours since pumping was stopped. The sharp rise in the absolute pressure could be due to cascading fracture.

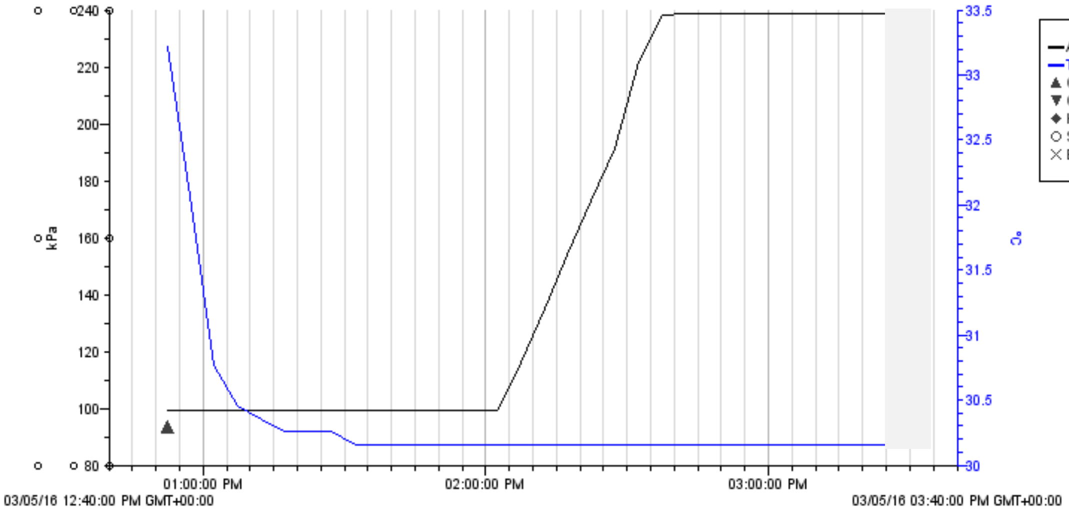

Figure 6: Effect of Rate of Kpaligung Borehole Recovery on Absolute Pressure

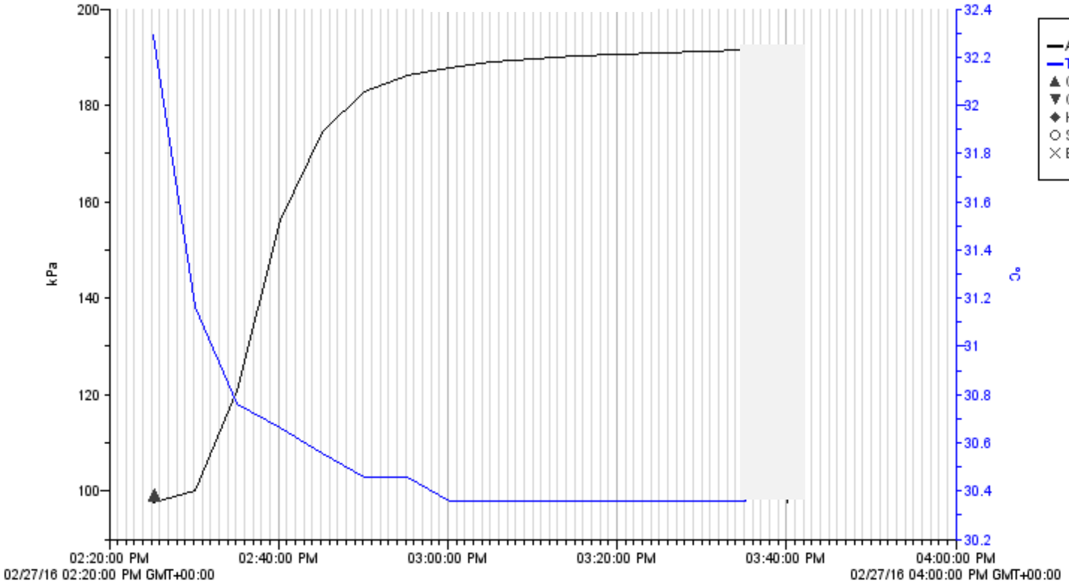

Figure 7: Effect of Rate of Baleofili Borehole Recovery on Absolute Pressure (Field measurements, 2016)

Relationship between Barometric Pressure and Water Pressure

Figures 7 and 8 present the relationship between barometric pressure and water pressure for Kpaligung and Baleofili boreholes respectively. Figure 7 shows the relationship between barometric pressure and water pressure for the Kpaligung borehole. Even though the coefficient of correlation shows a weak value (0.2), the graph shows a positive and direct relationship between barometric pressure and water pressure; increase in barometric pressure leads to an increase in water level and vice versa. This relation contradicts the assertion by Wardwell (2007) that, water level and barometric pressure of some boreholes are inversely related; increases in barometric pressure declines in observed water levels and vice versa. This phenomenon suggests that the Kpaligung borehole is not barometric efficient since the water pressure does not inversely respond to barometric change (Furbish, 1991). Domenico and Schwartz (1990) also indicated that, barometric responses are not commonly observed in wells completed within unconfined aquifer because pressures are evenly distributed between water levels within a well and the water table. This assertion confirms this finding that the Kpaligung borehole is on unconfined aquifer.

With respect to the Baleofili borehole, Figure 7 presents the correlation curve. Unlike the Kpaligung borehole, the graph of Baleofili borehole shows an inverse relationship between barometric pressure and water level pressure with the coefficient of correlation being 0.5. This confirms the assertion by Wardwell (2007) that water level and barometric pressure of some boreholes are inversely related; increases in barometric pressure declines in observed water levels and vice versa. This phenomenon suggests that the Baleofili borehole is barometric efficient, since the water pressure inversely responds to barometric change (Furbish, 1991). However, Domenico and Schwartz (1990) indicated that water levels have an inverse relationship to barometric pressure changes and are most commonly observed in confined aquifers because of the hydraulic gradient between the well and the surrounding aquifer. Even though the Baleofili borehole is on unconfined aquifer, this could be attributed to the assertion by MacDonald *et al.* (2005) that the aquifer properties away from the borehole are poorer than those closer to the borehole

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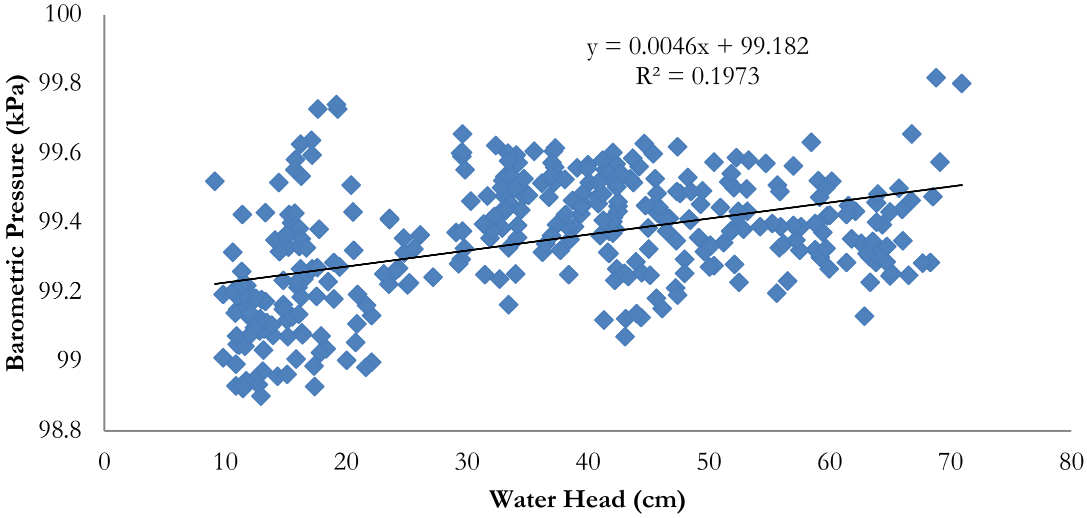

Figure 7: Relationship between Barometric Pressure and Water Pressure of Kpaligung Borehole

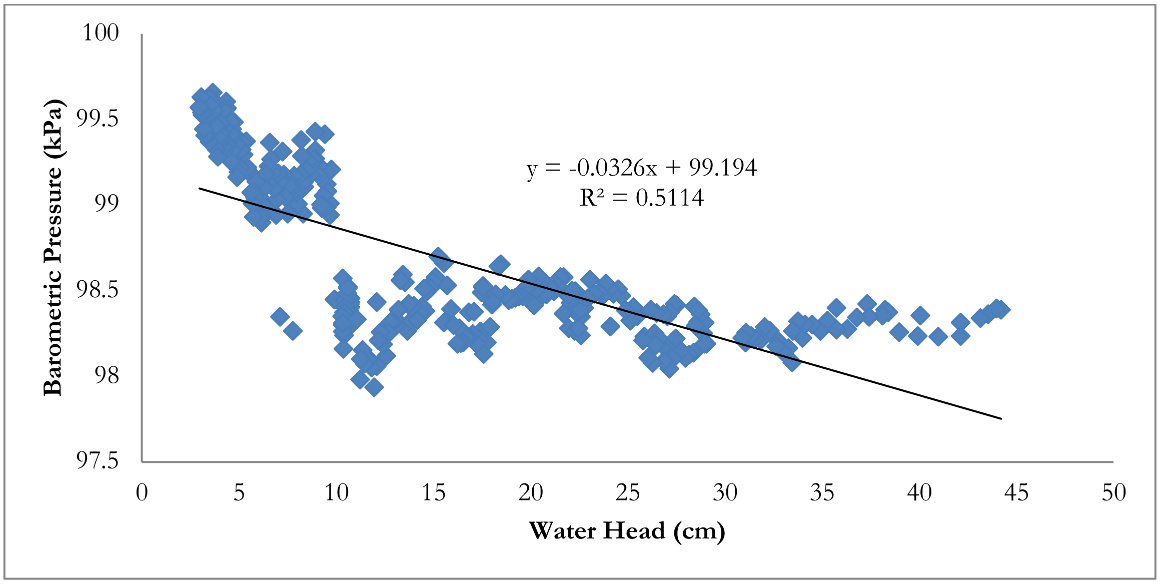

Figure 8: Relationship between Barometric Pressure and Water Pressure of Baleofili Borehole

Effect of Monthly Rainfall Amount on Water Pressure (Water Head) Fluctuations

Figures 9 and 10 presents the response of groundwater levels to rainfall variation at both

Kpaligung and Baleofili, respectively, in northern Ghana. Figures 9 and 10 show that the water levels start to increase as rainfall effectively starts after April and continuous until it reaches it's maximum in August-September when the rainfall also reaches its peak. After September, the water level in the boreholes begin to recess and this fall in water level continuous through to April in consonance with the reduction of rainfall from October at which time dry season begins to set in. The relationship between the changes in water level of the amount in Northern Ghana. Obuobie (2008) constructed a hydrologic model for the whole White Volta River basin using the Soil and Water boreholes with the corresponding change in rainfall amount suggests that the groundwater recharge of the boreholes depend considerably on rainfall variation in the areas. Previous studies have estimated groundwater recharge in different areas of northern regions. Most of the studies however have not identified the spatial distribution of recharge adequately. Friesen *et al.* (2005) indicate that for rainfall amount of 1005 mm, recharge is about 5 %. However, Carrier (2008) estimated 1.5 % - 15.9 % for 990 mm of rainfall

Assessment Tool (SWAT) model and found that recharge will increase by 29 % in the 2030's as a result of climate change impacts.

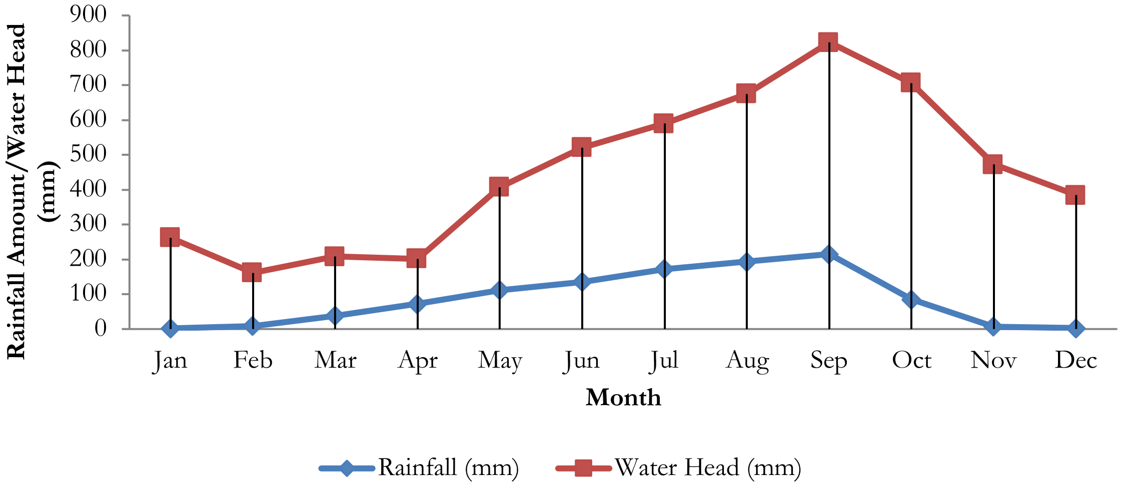

Figure 9: Effect of Monthly Rainfall Amount on Water Pressure of Kpaligung borehole

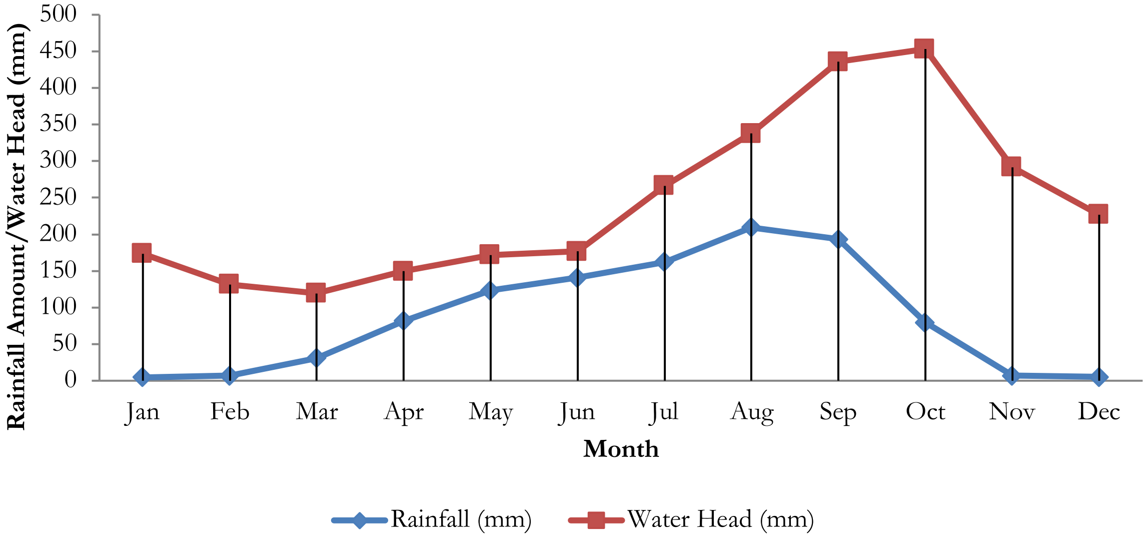

Figure 10: Effect of Monthly Rainfall Amount on Water Pressure of Baleofili Borehole

CONCLUSIONS

The steady state absolute pressure for Kpaligung borehole occurred when the absolute pressure reaches 99.42 kPa which is almost the same as the barometric pressure value of 99.25 kPa after 2 hours of continuous pumping of the borehole. This suggests that the borehole yield could be sustained even at a low water pressure (0.17 kPa) as pumping continuous. Unlike the Kpaligung borehole, Baleofili borehole attained a steady state at an absolute pressure of 152 kPa, which is above the barometric pressure value of 98 kPa, suggesting that the borehole yield could be sustained as pumping continuous with the water pressure of 54 kPa.

Rainfall regimes, as well as both absolute and barometric pressure have significant effect on Kpaligung and Baleofili boreholes` recharge and water-table fluctuations throughout the year.

The relationship between barometric pressure and water pressure for the Kpaligung borehole, even though the coefficient of correlation shows a weak value of 0.2, a positive and direct relationship between barometric pressure and water pressure; increase in barometric pressure leads to an increase in water level and vice versa. Unlike the Kpaligung borehole, the Baleofili borehole shows an inverse relationship between barometric pressure and water level pressure with the coefficient of correlation being 0.5.

The relationship between the changes in water level of the boreholes with the corresponding change in rainfall amount suggests that the groundwater recharge of the boreholes depends considerably on rainfall variation in the areas. The yields of the two boreholes are therefore enough for domestic water supply of the beneficiary communities

It is recommended that the following studies be conducted; spatial distribution of natural recharge to the aquifer system should be studied to determine the available water resources and that consequently, groundwater development activities can be better planned, more intensive monitoring and data gathering efforts should be undertaken to understand the groundwater resources in northern Ghana especially geology, aquifer system, and flow patterns and continuous water-level data observations are critical to understanding the short- and long-term trends and stresses in an aquifer.

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